Levels of Polychlorinated Biphenyls in Foods in Sweden

by Fredrik Berglund, M. D.*

PCBs have been used in industry in Sweden since 1929, initially only in electric transformers and capacitors, later also in paints, lacquers etc. The importation of PCBs to Sweden in 1970 was close to 500 tons. Approximately half of this amount was exported to other countries in electric capacitors. The use of PCBs in dyes was 65 tons in 1968 but was voluntarily diminished by industry to 35 tons in 1970. The Swedish Riksdag (parliament) has enacted the 1971 PCB Act, authorizing the government to prescribe conditions regarding importation, production, offering for sale and handling of PCBs, but detailed regulations have unfortunately not yet been published.

The high degree of persistence and lipid solubility of the PCBs have led to their accumulation in some foods of animal origin. In Sweden they now occur in the natural environment roughly in the same amounts as the chlorinated pesticides (1). The special hydrographical conditions of the Baltic favor the accumulation of PCBs in certain species and areas. The water exchange with the North Sea is very limited because of the thresholds (8 m and 18 m) and the narrowness of the Danish Sounds. The wide archipelagos at some places also make possible in some localities high concentrations of pollution, e.g., outside of Stockholm.

Table 1 briefly summarizes some of the earlier data, illustrating these points. The difference in levels of total DDT equivalents and PCBs between the Swedish west coast and the Baltic is more than 5-fold in fish oil and almost 10-fold in herring. The levels in fat are relatively high in all species shown. The role of the food-chain is shown by the high levels in seal and by the extremely high levels in the white-tailed eagles from the Stockholm archipelago. Their muscle fat contained about 2.5% of total DDT metabolites and 1.4% of PCBs. The Stockholm archipelago is evidently heavily contaminated (cf below). The very high levels of DDT and of PCBs in muscle fat compared with the levels in eggs are most probably due to sampling from unrelated individuals. The muscle samples were from sick birds, whereas the eggs derived from apparently healthy birds.

There are only few data from seal. The levels of ΣDDT and of PCBs per kg fat show fair agreement between seal pup and seal milk (from the stomach of one of the pups).

The samples were analyzed by gas chromatography and electron capture detection, combined with treatments with sulphuric acid and potassium hydroxide. The principle PCB components were found to have 7–14 chlorine atoms, with an increase of those with higher chlorine content as the PCBs passed along the food chain.

Analyses of PCBs were later taken up by Westöö & Norén (2). After extraction and routine clean-up, the extracts were separated by thin-layer chromatography into two groups, one of which contained PCBs and p,p′-DDE, o,p′-DDT, o,p′-DDE. The PCBs were determined by gas chromatography of this group, before and after oxidation of the organochlorine pesticides. Some of the PCBs were analyzed by gas chromatography without decomposition of the organochlorine compounds. Recoveries averaged 96–101% for PCBs added to purified fish extracts before application to thin-layer plate (2).

* Professor and head, Food Research Department, National Food Administration, 104 01 Stockholm 60, Sweden, as of January, 1972; former head, Department of Food Hygiene, same address.

Table 1. Average levels of organochlorine compounds in some Swedish marine organisms 1965–1968. Modified from (1).

Species	Locality	Fat content	ΣDDT mg/kg fat	mg/kg	PCB mg/kg fat	mg/kg
Herring	W. coast		1.9		0.75	
	Baltic (18)	4.4%	17	.68	6.8	.27
Fish oil	W. coast	100%	2		.7	
	Baltic	100%	16		3.5	
White tailed eagle						
muscle	Stockholm (4)	1.5%	25 000	330	14 000	190
eggs	Stockholm (5)	5.6%	1 000		540	
Seal	Gulf of Bothnia (2)	54%	120	63	13	6.8
Seal pup	Gulf of Finland (2)	60%	42	25	6.5	3.9
Seal milk	Gulf of Finland (1)	31%	36	11	4.5	1.4

Table 2. Levels of DDT, DDE, DDD and PCBs in some fish in Sweden 1967–1969. Modified from (2).

Fish	(n)	Range mg/kg	DDT n	DDE n	DDD n	PCB n
<4% fat freshwater	(87)	0–0.1	86	84	87	86
		0.1–1.0	1	3		1
<4% fat saltwater	(65)	0–0.1	57	59	65	58
		0.1–1.0	8	8		7
>4% fat saltwater	(34)	0–0.1	9	14	23	13
		0.1–1.0	24	20	11	19
		1.0–3.0	1			2

Table 3. Levels of organochlorine compounds in fish in Sweden 1967–1970. Modified from (3).

Species	Locality (No. of samples)	Fat content	ΣDDT mg/kg	PCBs mg/kg
Herring, *Clupea harengus*	Baltic (72)	3–20%	1.17±.061	0.49±.061
	S. Baltic, deep-frozen (16)	3–20%	1.40±.079	0.27±.017
Eel, *Anguilla anguilla*	Baltic (43)	25%	0.50±.038	0.28±.036
	W. coast (11)		0.26±.056	0.43±.134
Cod, *Gadus morrhua*	Baltic (30)	<2%	0.05 (0–0.2)	0.02 (0–0.1)
Cod liver	Baltic (7)	40–70%	10–22	2–5
	W. coast (3)		2–5	2–4
Salmon, *Salmo salar*	W. coast (5)	10–15%	0.06 (.04–.07)	Trace
	Lakes (5)	10–15%	2.63±.72	0.58±.177
Pike, *Esox lucius*	Lakes (37)	<2%	0.06 (0–0.3)	<0.1 (0–0.6)

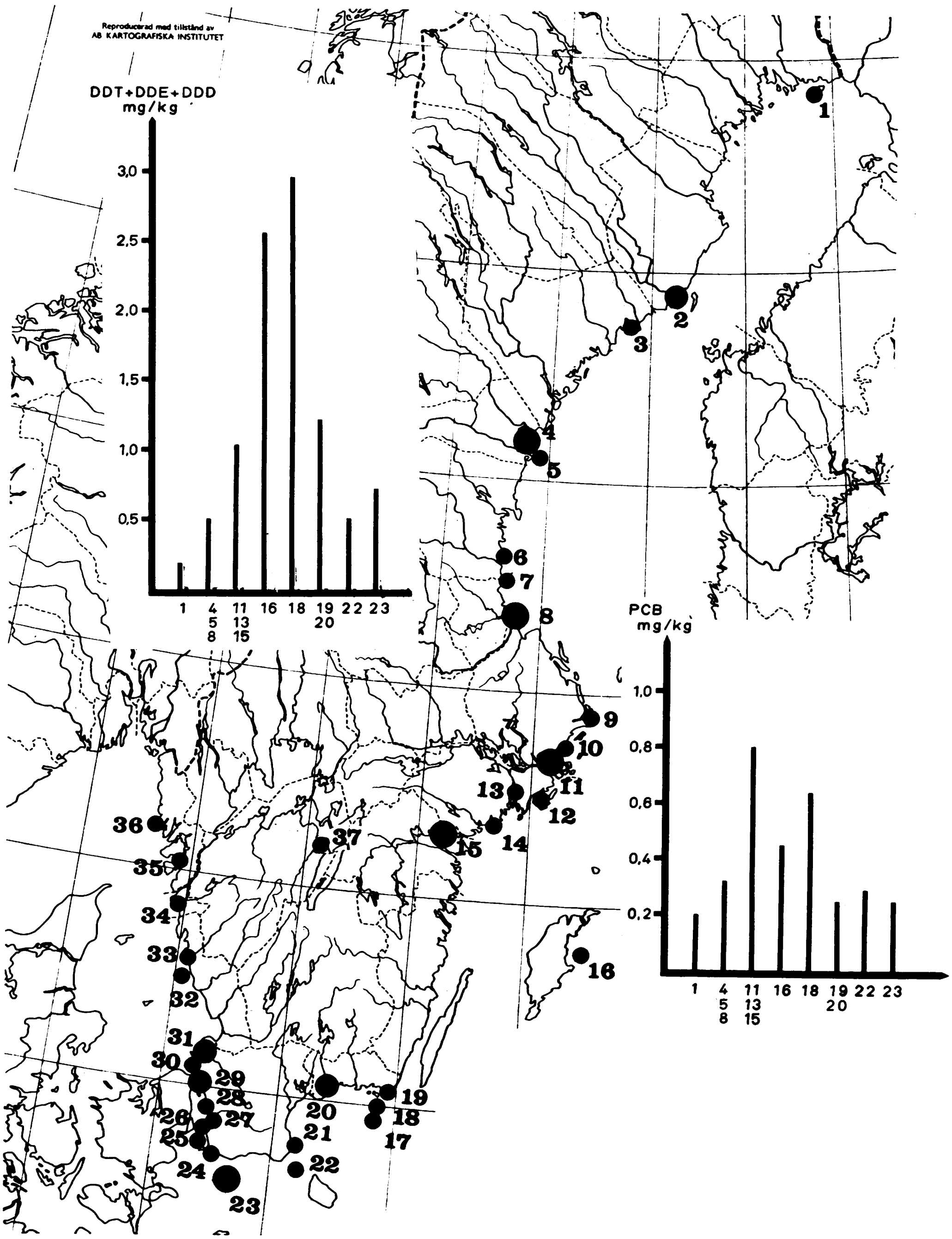

FIGURE 1. Average levels of organochlorine compounds in Baltic herring from different water areas. Modified from (3).

The preliminary survey of organochlorine compounds and PCBs in less than 200 samples of fish is summarized in Table 2. Levels of DDT, DDEs or PCBs above 0.1 mg/kg were only rarely seen in lean fish, i.e. in fish with less than 4% fat in their flesh, but occurred in more than half of the samples with more than 4% fat.

Westöö & Norén (3) later published analyses on about 1,000 samples of fish from lakes, rivers, the Baltic Sea and the Atlantic Ocean (Table 3).

Table 4. Levels of DDT, DDE and PCBs in some foods in Sweden 1967–1969. Modified from (4).

Food	(n)	Range mg/kg	DDT n	DDE n	PCBs n
Margarine	(115)	0–0.1	115	115	115
Vegetable oils	(197)	0–0.1	196	197	197
		0.1–1.0	1		
Beef	(34)	0–0.1	34	34	34
Lamb fat	(10)	0–0.1	10	10	10
Pork	(107)	0–0.1	101	104	106
		0.1–1.0	6	3	1
Chicken	(93)	0–0.1	93	93	93
Hen	(50)	0–0.1	50	49	50
		0.1–0.3		1	
Egg white[a]	(28)	0–0.1	28	28	28
Egg yolk[a]	(185)	0–0.1	176	176	183
		0.1–1.0	8	8	2
		1.0–6.0	1	1	

[a] Six in each sample.

The levels of ΣDDT and of PCBs depended on the fat content of the fish and on geographical location.

Regular salmon, *Salmo salar*, with 10–15% fat, had an average DDT level of 0.06 mg/kg on the west coast and 2.6 mg/kg in lakes, and of PCBs only traces on the west coast but 0.6 mg/kg in the lakes. Herring and eel, both with fairly high fat contents, had high levels. The highest PCB levels in fish were found in 2 small samples of herring from the Stockholm archipelago, 2.8 and 2.5 mg/kg, and in 4 yellow eels close to Gothenburg, 1.5 mg/kg. Five chars, *Salmo salvelinus*, in Lake Vättern had an average fat content of 7% and PCB level of 1.3 mg/kg (not included in Table 3).

Cod and pike, both with less than 2% fat, usually had very low DDT and PCB levels. Cod liver, on the other hand, with 40–70% fat, had high levels of DDT and PCBs. Because of its high levels of DDT, cod liver from the Baltic was declared unfit for human consumption by the Swedish health authorities this year (1971).

Some of the geographical variation of PCB and DDT levels in herring is shown in Fig. 1. PCB levels are highest outside of Stockholm, whereas DDT is higher off Gotland (16) and Blekinge (18–20). Other PCB-contaminated fish mentioned above were the eels caught off Gothenburg (34) and the chars in Lake Vättern (37).

In other foods the levels of DDT, DDE and PCBs were much lower than in fish (4), as shown in Table 4. With few exceptions, all the samples of the foods listed contained less than 0.1 mg/kg of each compound. Egg yolk showed some high levels, but PCB levels in whole eggs would still not be expected to exceed 0.1 mg/kg.

Table 5 shows the results of analyses on cow's milk, butter, and human milk. Analyses on cow's milk showed DDT less than 0.1, DDE less than 0.3 and PCBs less than 0.5 mg/kg on a fat basis. Analyses on a much larger number of samples of butter revealed levels of DDT below 0.13, of DDE below 0.1 and of PCB below 0.1 mg/kg, also on a fat basis. The difference between cow's milk and butter in terms of DDE and PCBs is probably only a matter of sensitivity of the method—there is no reason to suspect losses of DDE and PCBs in the churning process.

In the analysis of human milk there was no need to look for "human butter", since the levels of DDT, DDE and PCBs were much higher than in cow's milk. The DDT levels in whole milk show fair agreement with those in the U.S. (5) and England (6). The PCB levels average 0.5 mg/kg fat or 16 μg/kg whole milk. This average would probably only represent the Stockholm area, since all the samples originated from a "human milk donor center" in Stockholm.

Recently Westöö et al. (7) also discovered PCBs in some samples of cereal products. The origin was found to be the packaging material. On thin-layer chromatography and on gas chromatography, the PCBs behaved as PCBs of type Clophen A 60. In several samples of one kind of imported children's food, the PCB levels exceeded 1 mg/kg. In one sample of this product, which had been stored at room temperature for two years, the level of PCB had increased to 11 mg/kg. The sale of this children's food in Sweden was stopped in July, 1971.

The main intake of PCBs via the food in Sweden thus occurs by eating fish. The average consumption of fish in Sweden 1961–1969 was 17 kg/person/year—and of crustaceans and molluscs, about 1 kg/year. In terms of fish flesh Westin (8) calculated an intake for 1965 of 35 g per person and day. Of this, about 2 g represent

Table 5. Levels of DDT, DDE and PCBs in butter, cow's milk and human milk in Sweden 1967–1969. Calculated from (4).

Food (n)	Fat	DDT	DDE	DDT+DDE	PCBs
Cow's milk (11)	~3%	<0.1 mg/kg fat	<0.3 mg/kg fat		<0.5 mg/kg fat
Butter (154)	>81%	<0.13 mg/kg fat	<0.1 mg/kg fat		<0.1 mg/kg fat
Human milk (22)	3.25 ±0.11%	1.24±0.07 mg/kg fat 40±3.0 μg/kg milk	2.08±0.13 mg/kg fat 67±6.0 μg/kg milk	3.32±0.19 mg/kg fat 106±8.8 μg/kg milk	0.50±0.039 mg/kg fat 16±2.5 μg/kg milk

freshwater fish, 1 g caviar, and 1 g shellfish and molluscs together. The average intake of PCBs therefore probably does not exceed 1 μg per day but may well exceed 10 μg/day in people eating herring from the Baltic 3 times a week.

A suckling baby ingests about 0.15 litre of mother's milk per kg body weight daily in the 2nd and 3rd months of life, with an average PCB level of 15 μg/kg milk. This corresponds to 2.4 μg/kg body weight per day. Thus we have a situation similar to that with DDT with the suckling baby getting the highest exposure. Also, it is known from Japan that PCBs pass the placental barrier (9).

Conclusions. Proper food processing should not produce PCB levels higher than 0.1 mg/kg food, except in fish with more than 2% fat in edible portions. Human milk has low levels of PCBs, but due to the high intake of milk, the suckling baby will experience the heaviest exposure.

To avoid further food contamination in the future, the use of PCBs should only be allowed in closed systems and under most careful supervision. Less dangerous substitutes should be looked for in industry.

REFERENCES

1. Jensen, S. et al. 1969. DDT and PCB in marine animals from Swedish waters. Nature 224: 247.
2. Westöö, G. and Norén, K. 1970. Determination of organochlorine pesticides and polychlorinated biphenyls in animal foods. Acta. Chem. Scand. 24: 1639.
3. Westöö, G. and Norén, K. 1970. Levels of organochlorine pesticides and polychlorinated biphenyls in fish caught in Swedish water areas or kept for sale in Sweden. Vår Föda 22: 93.
4. Westöö, G., Norén, K. and Andersson, M. 1970. Levels of organochlorine pesticides and polychlorinated biphenyls in margarine, vegetable oils, and some food products of animal origin on the Swedish market in 1967–1969. Vår Föda 22: 9.
5. Quinby, G. E., Armstrong, J. F. and Durham, W. F. 1965. DDT in human milk. Nature 207: 726.
6. Egan, H. et al. 1965. Organochlorine pesticides residues in human fat and human milk. Br. Med. J. 2: 66.
7. Westöö, G., Norén, K. and Andersson, M. 1971. Levels of organochlorine pesticides and polychlorinated biphenyls in some cereal products. Vår Föda 23: 341.
8. Westin, S. I. 1969. Reviewed in: F. Berglund et al. 1971. Methyl mercury in fish. A toxicologic-epidemiologic evaluation of risks. Report from an expert group. Nord. Hyg. Tidskr., Suppl. 4: 252.
9. Tsukamoto, H. et al. 1969. The chemical studies on detection of toxic compounds in the rice bran oils used by the patients of Yusho. Fukuoka Acta Med. 60: 497.